PATENT SPECIFICATION

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Date of Application and filing Complete Specification: January 30, 1961. No. 3437/61

Two Applications made in United States of America (Nos. 7,252 and 7,276) on February 8, 1960.

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International Classification:—G 01 r (H 03 k, H 04 b).

COMPLETE SPECIFICATION

DRAWINGS ATTACHED

Adaptive Recognition Method and System

We, General Electric Company, a corporation organized and existing under the laws of the State of New York, United States of America, of 1 River Road, Schenectady 5, New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method and system for recognizing and storing one or more repetitive signals occurring at random times in a background of noise.

One of the problems confronting the present day designer of electrical systems is to design a system which will recognize a signal whose characteristics are not fully known in advance. For example, present day digital computers are capable of handling only that information which is inserted into the computer in the form of a predetermined signal pattern or signals having a predetermined wave form. As another example, some communication systems are designed to recognize signals having only wave forms of a predetermined shape. If the wave form of this signal is altered, such a communication system is ineffective to recognize that signal. There are many applications where it would be desirable to have a system which would recognize recurrent signals even though the frequency of recurrence or the characteristics other than that, for example, of its repetition rate is not fully known beforehand. In addition, there are many applications where it is desirable to classify signals in accordance with the characteristics of the signals.

Accordingly there is provided a method for recognizing recurring signals with increasing accuracy and capable of distinguishing recurring signals from random noise and other signals supplied by an input so that the identification of the recurring signals becomes progressively more accurate, comprising the steps of initially storing amplitude characteristics derived from the input consisting of time spaced values of input signal amplitudes, comparing the same characteristics derived from subsequent inputs with the stored characteristics and combining the subsequent characteristics with those in storage to provide revised stored characteristics if, and only if, a correlation exists between the compared characteristics, and repeating the comparing and combining steps whereby the recurring signals emerge from the other input signals.

There is further provided an adaptive signal recognition system for carrying out the above method comprising an adaptive filter having storage means for retaining an amplitude characteristic of the input, for a predetermined length of time, means for comparing the same characteristics of subsequent inputs with the stored characteristic, and combining means for altering the retained characteristic by the combination therewith of the same characteristic derived from subsequent inputs whenever a correlation exists between the compared characteristics to achieve progressively better signal recognition.

In accordance with a preferred embodiment of the present invention each adaptive filter of the system stores information indicative of the input and this information is adjusted in accordance with the signal

[Price 4s. 6d.]

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ERRATUM

SPECIFICATION NO. 971,109

Page 1, Heading U.S.A. Application No. *for* "7252" *read* "7275"

THE PATENT OFFICE,
19th February, 1965

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Schenectady 5, New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method and system for recognizing and storing one or more repetitive signals occurring at random times in a background of noise.

One of the problems confronting the present day designer of electrical systems is to design a system which will recognize a signal whose characteristics are not fully known in advance. For example, present day digital computers are capable of handling only that information which is inserted into the computer in the form of a predetermined signal pattern or signals having a predetermined wave form. As another example, some communication systems are designed to recognize signals having only wave forms of a predetermined shape. If the wave form of this signal is altered, such a communication system is ineffective to recognize that signal. There are many applications where it would be desirable to have a system which would recognize recurrent signals even though the frequency of recurrence or the characteristics other than that, for example, of its repetition rate is not fully known beforehand. In addition, there are many applications where it is desirable to classify signals in accordance with the characteristics of the signals.

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noise and other signals supplied by an input so that the identification of the recurring signals becomes progressively more accurate, comprising the steps of initially storing amplitude characteristics derived from the input consisting of time spaced values of input signal amplitudes, comparing the same characteristics derived from subsequent inputs with the stored characteristics and combining the subsequent characteristics with those in storage to provide revised stored characteristics if, and only if, a correlation exists between the compared characteristics, and repeating the comparing and combining steps whereby the recurring signals emerge from the other input signals.

There is further provided an adaptive signal recognition system for carrying out the above method comprising an adaptive filter having storage means for retaining an amplitude characteristic of the input, for a predetermined length of time, means for comparing the same characteristics of subsequent inputs with the stored characteristic, and combining means for altering the retained characteristic by the combination therewith of the same characteristic derived from subsequent inputs whenever a correlation exists between the compared characteristics to achieve progressively better signal recognition.

In accordance with a preferred embodiment of the present invention each adaptive filter of the system stores information indicative of the input and this information is adjusted in accordance with the signal

subsequently received in a way which takes into account the number of times a particular signal is received and the length of time between successive receptions of the signal in such a way that the noise is eliminated. In other words, the adaptive filter automatically forgets signals which do not occur for long periods of time and establishes stored information corresponding to a signal which is repeatedly received.

In accordance with a further embodiment of the invention, an electrical input including an unknown signal plus noise is impressed on a delay line. By this means, the changes that occur over a period of time corresponding to the length of the delay line may be made available at a number of taps provided on the delay line. The values of the signals at each of the taps are sampled by sampling capacitors. Also associated with each tap is a storage capacitor and a multiplier for multiplying the signal at the tap by the signal stored on the storage capacitor. The outputs of the multipliers associated with all taps are added to obtain a continuous correlation function between the stored samples and the continuous signals at the taps of the delay line. Peak values of the correlation function passing through a threshold detector operate to effect a switching operation which connects each of the sampling capacitors in parallel with its associated storage capacitor to bring these capacitors to voltage equilibrium. The threshold of operation of the threshold detector varies automatically in accordance with the interval between successive operations. As the interval gets shorter and the stored information more closely duplicates the received signal, the threshold is then higher and the contents of storage are adjusted only for higher values of the correlation function than would be required with a fixed threshold of operation. The switching of the capacitors effects a weighted averaging of the voltages on the capacitors, the weighting depending upon the ratio of the capacities of the two capacitors. In accordance with another embodiment of the invention, a plurality of adaptive filters are connected together to form an adaptive system which recognizes and stores a plurality of signals contained in the input.

In the accompanying drawings:

Fig. 1 is a block diagram showing the broad concept of the invention;

Fig. 2 is a schematic representation of an adaptive filter embodying the invention;

Fig. 3 is a set of waveform diagrams illustrating the operation of the adaptive filter in storing a signal contained in an input which also contains noise wherein;

Fig. 3a is a waveform diagram of the signal by itself;

Fig. 3b is a waveform diagram of the noise by itself;

Fig. 3c is a waveform diagram of the input containing the signal and the noise;

Fig. 3d is a waveform diagram of a random sample which is inserted into storage in the system to prime the system prior to the initiation of operation;

Fig. 3e is a waveform diagram of the signal in storage at a first instant of time;

Fig. 3f is a waveform diagram of the signal in storage at a second instant of time;

Fig. 3g is a waveform diagram of the signal in storage at a third instant of time;

Fig. 3h is a waveform diagram of the signal in storage at a fourth instant of time;

Fig. 3i is a waveform diagram of the signal in storage at a fifth instant of time;

Fig. 3j is a waveform diagram of the correlation function;

Fig. 4 is a set of curves which indicate the manner in which the system adapts itself to new signals;

Fig. 5 is a block diagram of an adaptive system comprising a plurality of adaptive filters; and

Fig. 6 is a diagram, partly schematic, of two adaptive filters connected to form an adaptive system.

The broad concept of the adaptive filter can be described briefly in conjunction with Fig. 1 which is a block diagram of the filter. The input, containing a repetitive information signal which is to be recognized together with noise which may be present, is fed into a delay line 1. To begin the recognition process a random portion of the input is placed in storage in a storage unit 2. The contents of storage are then continuously compared with time-spaced values of the input at various taps along the delay line 1. This comparison takes place in a correlator 3 which will produce a signal indicative of the correlation between the contents of storage and the input, which is fed into the delay line. If a high correlation exists between the contents of storage and the input, the output of the correlator will be above a certain minimum level which will be detected by a threshold detector 4. In such a case, the threshold detector 4 will activate an arithmetic unit 5 so that the input, which has a high correlation with contents of storage, will be placed in storage. The arithmetic unit places the input into storage in a weighted manner so that the contents of storage will always be weighted slightly in favor of the most recent input. In this manner, a weighted arithmetic averaging of the input containing signal and noise with the contents of storage is achieved. The results of this operation are such that the noise

is minimized and the contents of storage become essentially the desired information signal without the noise after a suitable number of switching operations of the arithmetic unit. By weighting the most recent input, it is possible to introduce forgetting into the filter so that it will adapt itself to the most recent signal.

The circuit of the adaptive filter is illustrated in more detail in Fig. 2. Referring to Fig. 2, a delay line illustrated schematically as including an elongated inductive element 10 surrounded by a grounded cylindrical conductor 11 is provided with a number of taps 12, 13 and 14, equally spaced and equal in number to the number of sampling points desired. It is apparent that this delay line forms a way of providing, on the individual taps, voltages corresponding in magnitude to the input voltages that occur over a period of time equal to the delay interposed by the delay line. In other words, the delay line provides temporary storage from which the incoming signal may be sampled or "read out". A mechanical commutator or other electronic switching device may be used in place of the delay line to feed signals to the various taps. The voltage on each of the taps is continuously sampled by sampling capacitors designated as 15 and also is continuously applied as an input to a multiplier 16 by an input conductor 17. A second input to the multipliers 16 is supplied by conductors 18 from storage capacitors 19. These inputs are impressed on conductors 17 and 18 through a pair of cathode follower circuits designated generally by the numeral 20. The outputs of the multipliers, which are proportional, respectively, to the products of the voltages appearing at the taps 12, 13 and 14 of the delay line and the voltages appearing on the corresponding storage capacitors 19, are supplied through a network including resistors 21 to a direct current amplifier designated generally at 22. The resistors 21 are connected together to provide a single input to the direct current amplifier 22. The output of this amplifier is then a function of the sum of the voltages appearing at the outputs of the multipliers 16, and when a maximum occurs in this voltage it is an indication that the sum of the product of the voltages appearing at the sampling taps 12, 13 and 14 and the voltages previously stored on the corresponding capacitors 19 is a maximum. This voltage is designated e_{in}, the correlation function. It will be recognized by those skilled in the art that this voltage is indicative of the cross correlation between the stored and sampled voltages.

The output of the amplifier 22, e_{in}, is supplied through a threshold detector 23 to provide a keying voltage pulse for a pulse generator 24 whenever the output of the amplifier 22 reaches a peak greater than the previous peak output of this amplifier. The threshold detector 23 together with the pulse generator 24 produce an output pulse each time the correlation function e_{in}, reaches a peak greater than the previous peak of e_{in}. The threshold detector 23 compares the input to the detector, designated as e_{in}, with a value, designated as $e_{in}/_{max}$, indicative of the maximum value that the input has previously attained. The value of $e_{in}/_{max}$ may be less than the previous value of e_{in}, as explained more fully below. The output of the amplifier 22 is fed to the threshold detector 23 through variable resistor 25 and diode 25[1]. The tap on variable resistor 25 is connected to a diode 26 and the cathode of diode 26 is connected to a capacitor 27 which stores peak values of the voltage e_{in}. The voltage on the capacitor 27 is designated e_1.

The voltage e_{in}, taken from the cathode of the diode 25[1], is connected through a resistor 28 to an inverting amplifier 29. The inverted value of e_{in} is added to the voltage e_1 from the storage capacitor 27. These two voltages are connected through resistors 32 and 33 respectively, to a common junction at which point the addition takes place. The result of this addition is again inverted by an inverting amplifier 31; the output of this amplifier being designated e_{out}. A clipping diode 35 shunts all positive values of e_{out} above a given value to ground through a resistor 36.

The values of e_{out} are connected to the pulse generator 24. This pulse generator 24 preferably comprises a Schmitt trigger circuit, the output of which is differentiated and amplified and connected to the relay circuits. The Schmitt trigger may be of the type shown and described on pages 99, 100, 101, 102 of "Electronics" by Elmore and Sands, McGraw Hill, 1949. The circuit shown in Figure 2.37 of this reference may be used exactly as shown except that the values of e_{out} should be inverted before being fed to the input of this circuit and the +300 volts and ground potential reference levels of the circuit shown by Elmore and Sands should be changed to +200 volts and −100 volts, respectively, so that the triggering takes place around zero volts input.

The operation of the threshold detector 23 can best be described as follows. The voltage e_{in} applied to the threshold detector 23 is connected through diode 26 to capacitor 27 and charges capacitor 27 to a voltage indicated as e_1 in Fig. 2. Note that e_1 is always indicative of the previous maximum of the voltage e_{in} because the

diode 26 prevents discharge of capacitor 27.

The value e_1 may correspond to the previous maximum of voltage e_{in} or a predetermined fraction thereof depending upon the setting of the tap on resistor 25. The voltage e_1 is added to the inverted value of e_{in} taken from the inverting amplifier 29. The result of this addition is again inverted by the inverter 31 and the output of this amplifier is designated e_{out}. All positive values of e_{out} above a predetermined value are clipped by the clipping diode 35. The waveform designated e_{out} is connected to a Schmitt trigger. If the output of the Schmitt trigger is differentiated and the negative values clipped from the output, the pulse generator 24 produces a positive output pulse coincidentally in time with the peaks of the correlation function e_{in}. That is, the first output pulse of the pulse generator 24 corresponds in time with the first peak, in the correlation function e_{in}.

The operation of threshold detector 23 can be varied slightly by changing the setting of variable resistor 25. By so doing, the capacitor 27 is charged to a fraction of the peak value of e_{in} and the time at which the pulse generator 24 produces an output with respect to peaks in the voltage e_{in} is changed. That is, the pulse generator 24 will then produce an output slightly in advance of peaks in the voltage e_{in}.

The firing level and resetting level of the Schmitt trigger can also be varied slightly. The variation of this firing level is best explained in "Electronics" by Elmore and Sands previously referenced but it can readily be seen that such a variation increases or decreases the sensitivity of the pulse generator 24 to peaks in the voltage e_{in}.

The pulse generator 24 energized the thyratron controlled relay circuits designated generally by the numeral 37 of Figure 2. Each relay circuit 37 is associated with one of the sample taps 12, 13 and 14 and is operable to actuate relays each of which has a normally open set of contacts 38 and a normally closed set of contacts 39. When the relays are actuated, these contacts will interrupt momentarily the connection of sampling capacitor 15 with the delay line tap and connect it with the storage capacitor 19 to bring the voltages on these two capacitors to voltage equilibrium. This operation takes place each time a maximum occurs in the correlation function to bring the capacitors to voltage equilibrium and, in this way, effect an adjustment of the voltage on the capacitor 19. The number of samplings required to bring the capacitors 19 to a voltage corresponding to the signal is determined by the ratio of the capacities of the capacitors 15 and 19 and the character and amount of the noise in the input signal. A resistance 40 connected in parallel with each of the storage capacitors 19 determines the rate at which the storage capacitor is discharged and in this way determines the rate of forgetting, that is, the rate at which any charge corresponding to a signal which does not recur for a long period of time disappears from the pattern of voltage on the storage capacitors.

The output of the adaptive filter is taken from a commutator 41 which successively samples the voltage on each of the storage capacitors 19. Each storage capacitor is connected through its associated cathode follower 20, to one of the contacts 42, 43, 44 of the commutator 40. The rotor 45 of the commutator rotates continuously thus selectively connecting each of the storage capacitor voltages to the output which is taken from the rotor 45. The commutator rotor 45 rotates at a speed commensurate with the number of storage capacitors in the system and the duration of the signal which is being observed to provide a combined output which is indicative of the repetitive signal contained in the input. While a mechanical type commutator has been shown in Fig. 2, it should be understood that any suitable electronic sampling device could also be used.

Although a commutator with six contacts has been shown, the commutator will have as many contacts as there are storage capacitors in the adaptive filter. Thus, an adaptive filter having N storage capacitors will have a commutator with N contacts. It can be readily seen that such an adaptive filter would also have N cathode followers, N multipliers, N relay circuits, N sampling capacitors and a delay line have N taps.

The operation of the adaptive system in recognizing and storing a signal and rejecting the noise can best be understood by reference to the waveforms of Fig. 3. In all of the waveforms of Fig. 3, the time, T, is indicated in increments which are equal to the time delay between each tap of the delay line. The waveforms of Fig. 3 represent a hypothetical situation in which the input comprises a signal plus a small amount of noise. In Fig. 3a there is shown a signal which varies between +3 volts and −3 volts. This signal is repetitive but occurs randomly as shown in Fig. 3a. The input also contains noise which is shown in Fig. 3b. For this example the noise is shown as being between +1 and −1 volt. The noise also occurs randomly. The waveform of Fig. 3c is the algebraic sum of the signal of Fig. 3a and the noise of Fig. 3b. The waveform of Fig. 3c thus represents the composite input or the sig-

nal plus noise. For the purpose of illustration there is shown an input having a fairly high signal to noise ratio but the system is capable of recognizing and storing signals which are completely buried in noise.

In Fig. 3d there is shown a random sample of signal plus noise which is initially put into storage in the storage capacitors. For the purposes of this example it will be assumed that the adaptive filter comprises eight storage capacitors. The value of this waveform at 47 indicates the value stored in the first storage capacitor, the value of the waveform at 48 is the value stored in the second storage capacitor, the value of waveform at 49 is the value stored in the third storage capacitor and so on. The waveform of Fig. 3e shows the voltages stored on these eight capacitors after the first peak in the correlation function shown in 3j has been detected thus transferring the input from each sampling capacitor to the corresponding storage capacitor.

In the above illustration the weighting of the voltage on the sampling capacitor relative to that of the storage capacitor has been carried out with an operation

$$M_{(k+1)} = \frac{(M_k + S_k)^k}{k+1}$$

where M_k is the sampled value representative of any storage tap and S_k is a value of voltage transferred into storage, k being the number of times the operation has been performed, that is, the number of peaks in the correlation function that have occurred. Similarly, Fig. 3f shows the values in storage after the second peak in the correlation has been detected, Fig. 3g represents the values in storage after the third peak in the correlation. Fig. 3h represents the values in storage after the fourth peak and Fig. 3i represents the values in storage after the fifth peak in the correlation function has been detected. The correlation function itself e_{in}, of Fig. 2 is shown in Fig. 3j. The maximum values of the correlation function, $e_{in}/_{max}$, are indicated by the dotted lines drawn from each of the peaks. It will be noted that $e_{in}/_{max}$ is an exponential curve from each peak in the correlation function indicating that a slight decay has been built into the threshold detector. Each time that the correlation function exceeds one of the dotted lines the contents of storage are modified by connecting the sampling capacitors to the storage capacitors. Note that the firing does not take place at the intersection of the dotted curve and the correlation function but that the firing is delayed until the next peak occurs after this intersection as explained in connection with the operation of the threshold detector. The correlation function e_{in} has been drawn carefully in Fig. 3j so that it can be seen that it is equal to the sum of the products of the contents of storage of each of the capacitors times the value of the input appearing at the tap associated with that storage capacitor at all times.

After the initial random priming sample, shown in Fig. 3d, has been inserted into the storage capacitors, the steady state operation of the adaptive system in recognizing the particular signal begins. At time T = 0, the correlation function, Fig. 3j, has reached a peak of +2 volts. The threshold detector 23 of Fig. 2 will detect this peak and will actuate the pulse generator 24. In turn, the pulse generator 24 will actuate the various relay circuits thus connecting the sampling capacitors 15 to the storage capacitors 19. The contents of storage will be modified so that the new values in storage will be as shown in Fig. 3e.

The correlation function, Fig. 3j, will next exceed $e_{in}/_{max}$ at time approximately T = 5. This may be seen from the intersection of the correlation function e_{in} with the dotted line $e_{in}/_{max}$ which indicates the slight delay from the previous peak of +2 volts stored in the threshold detector 23. At this time the contents of storage will again be modified as described above so that the new contents of storage will be as indicated in Fig. 3f. Similarly, the correlation function exceeds the maximum value previously stored in the threshold detector at times T = 11; T = 23 and T = 30. At these times the contents of storage will again be modified and the resultant contents of storage at each of these times are shown in Figs. 3g, 3h and 3i. The output of the commutator 41 of Figure 2 will be the waveform shown in Figs. 3d through 3i at the times for which these figures are drawn in the diagram. A comparison of Figs. 3e through 3i will show that the contents of storage represent a continuously better picture of the transmitted signal. The waveform of Fig. 3i is an almost exact picture of the transmitted signal, shown in Fig. 3a, without the noise of Fig. 3b.

Each time there is a peak in the correlation function, e_{in}, of Figure 3j the sampling capacitor 15 will be connected to the storage capacitor 19, resulting in a new average value being placed in storage. The new voltage on the storage capacitor 19 will be weighted in a manner which depends upon the ratio of the capacitance of the storage capacitor 19 to the capacitance of the sampling capacitor 15. This ratio may be denoted by the letter n. If n is quite large, the input previously stored will be given great weight in determining the

new voltage on the storage capacitor. However if n is quite small, the voltage on the sampling capacitor is given great weight in determining the new voltage on the storage capacitor. A better idea of the weighting which takes place in the averaging process can be obtained with reference to Fig. 4. It can be shown mathematically, that the weight which is given to each sample can be represented by $\left(\frac{n}{n+1}\right)^k$ where n is the ratio of the capacitance of the storage capacitor to the capacitance of the sampling capacitor as previously mentioned and k is the number of times new information has been inserted into storage or the number of repetitions of the signal. In order to obtain some appreciation of the weight of each value which is inserted into storage compared to weight of the k previous values which have been inserted into storage there is included in Fig. 4 curves of the quantity $\left(\frac{n}{n+1}\right)^k$ as a function of k for different values of n. This family of curves represents the weight given to the k previous values inserted into storage for different values of n. Referring to the curve 60, we can determines the weight given to the previous samples when n, the ratio of the capacitance of the storage capacitors to the capacitance of the sampling capacitors, is equal to 5. For example, the weight given for five previous samples, k = 5, is 0·4 and the weight given to the ten previous samples is 0·15. As another example, if n = 1, then the most recent sample, k = 1, is given a weight of 0·5 while the two previous samples, k = 2, are given a weight of 0·3. The curves of Fig. 4 are quite useful in understanding how the system adapts itself to a continuously changing signal. If n is chosen to be quite small, for example, n = 5, then the system is extremely adaptive and the contents of storage reflect, primarily, the most recent information which has been inserted into storage. However, the smaller values of n will not give a signal in storage which has a good definition of signal to noise. That is, the contents of storage will also reflect the noise which is contained in the more recent samples. On the other hand, if n is chosen to be quite large, for example n = 40, then a very good definition of signal to noise will be obtained in the contents of storage. This is because previously stored samples are given greater weight and the random noise contained in the large number of previous samples has cancelled out to a considerable extent. It can be seen that by varying n, the desired adaptiveness and definition of signal to noise can be obtained. If a number of different repetitive signals are contained in the input it would, of course, be desirable to recognize and store all of these signals.

In accordance with the embodiment of the invention shown in Fig. 5 a plurality of the adaptive filters previously described are connected to form an adaptive system which recognizes and stores a number of different repetitive signals contained in the input.

Referring to Fig. 5 there is shown a block diagram showing the broad aspect of such a system. In this system the input containing the signals plus the noise is fed into a delay line 50. The output of the delay line is fed in parallel to a number of adaptive filters. As shown in Fig. 5 three adaptive filters, 51, 52, and 53, are connected in parallel. Just as in the adaptive filters described above, the adaptive filter 51 comprises a storage unit 54 into which a random portion of the input is placed to begin the recognition process. The contents of storage are continuously compared with the input from the delay line 50. This comparison takes place in a correlator 55 which will produce a signal indicative of the correlation between the contents of the storage unit and the input which is fed into the delay line. If a high correlation exists it will be detected by a threshold detector 56. In such a case the threshold detector 56 will activate an arithmetic unit 57 so that the input will be placed in storage. The adaptive filters 52 and 53 are similar to the adaptive filter 51.

In order to prevent more than one adaptive filter from recognizing a given input signal adaptive filter 52 is additionally provided with an examination circuit in the form of an inhibit circuit 58 and adaptive filter 53 is additionally provided with an examination inhibit circuit 59. The output of the threshold detector 56 in the adaptive filter 51 is connected to the inhibit circuit 58 in adaptive filter 52 and to the inhibit circuit 59 in adaptive filter 53. Once the adaptive filter 51 has recognized a given signal the output of the threshold detector 56 will inhibit the adaptive filters 52 and 53 from recognizing this given signal.

In a similar manner the output of the threshold detector in the adaptive filter 52 is connected to the inhibit circuit 59 in the adaptive filter 53. Because of this connection, once the adaptive filter 52 has recognized a signal, adaptive filter 53 will be inhibited from also recognizing this signal. It can readily be seen that for an adaptive system including a number of q adaptive filters, a numeral q-1 of inhibit circuits are

required to prevent succeeding adaptive filters from recognizing a signal already being recognized by a preceding filter.

Referring to Fig. 6 there is shown a more detailed drawing of the manner in which two adaptive filters are connected together to form an adaptive system. The input containing the signals and noise is connected to a delay line 61. The outputs of the delay line, taken from taps 62, 63, and 64 are connected in parallel to adaptive filter 65 and adaptive filter 66. Adaptive filter 65 comprises relay circuits 67, cathode followers 68, multipliers 69, sampling capacitors 70, and storage capacitors 71 connected to each tap of the delay line 61. In addition, adaptive filter 65 is provided with a threshold detector 72 and a pulse generator 73.

Adaptive filter 66 comprises similar circuitry and in addition is provided with an inhibit circuit 74. In order to inhibit adaptive filter 66 from recognizing a signal which adaptive filter 65 has already recognized, the output of pulse generator 73 in adaptive filter 65 is connected to inhibit circuit 74 through a resistor 75. In order to clip the output of pulse generator 73 to a +5 volt level, the resistor 75 is connected through a clipping diode 76 to a +5 volt clipping voltage 77 which is in turn connected to ground potential.

The output of the pulse generator in adaptive filter 66 is also connected to the inhibit circuit 74. The output of this pulse generator is connected through a resistor 78 to an inverting amplifier 79. The inverted output of the pulse generator is clipped to a −5 volt level by means of a clipping diode 80 which is connected to a −5 volt clipping voltage 81 which is in turn connected to ground potential. The output of the pulse generator 73 in adaptive filter 65 is added to the inverted output of the pulse generator in adaptive filter 66 by connecting these two outputs together through resistors 82 and 83. The result of this summation is inverted by means of an inverting amplifier 84 and all negative values of the output of this amplifier are shorted to ground by means of the clipping diode 85. The output of inhibit circuit 74, taken from the output of the inverting amplifier 84, is connected to energize all of the relay circuits of adaptive filter 66.

The operation of the adaptive system of Fig. 6 is as follows:

Adaptive filter 65 recognizes and stores a given priming signal in the manner previously described in conjunction with the single adaptive filter. Each time adaptive filter 65 recognizes this given signal (in the steady state phase of operation) pulse generator 73 produces an output which inhibits inhibit circuit 74 in adaptive filter 66. The positive pulse from pulse generator 73 is clipped to +5 volts by the clipping diode 76. The examination phase of the system begins when adaptive filter 66 begins recognition of the same signal as recognized by adaptive filter 65. Should this occur the pulse generator in adaptive filter 66 produces a pulse coincidentally in time with the pulse from pulse generator 73. The pulse from the pulse generator in adaptive filter 66 is inverted by inverting amplifier 79 and clipped to a −5 volt level by the clipping diode 80. When the +5 volt pulse from pulse generator 73 and the −5 volt pulse from the pulse generator in adaptive filter 66 are added together through the resistors 82 and 83, they cancel each other and the output of inverting amplifier 84 is zero. Therefore, the relay circuits of adaptive filters 66 will not be actuated; that is, adaptive filter 66 is inhibited from recognizing and storing this particular signal. If, on the other hand, adaptive filter 66 recognizes a signal different from that recognized by adaptive filter 65, that is, one which occurs at a different time, the output of the pulse generator in adaptive filter 66 will pass through the inverting amplifier 79; it will not be cancelled by a coincident pulse from pulse generator 73 in adaptive filter 65; it will again be inverted by the amplifier 84; and the resultant output will actuate the relay circuits in adaptive filter 66. In such a case the adaptive filter 66 is not inhibited from recognizing this signal.

While only two adaptive filters have been shown connected to form an adaptive system in Fig. 6, it should be understood that a large number of adaptive filters can be connected together to form adaptive system and that each adaptive filter is connected to inhibit all succeeding adaptive filters from recognizing the same signal which is being recognized in that adaptive filter. A summary of the operation of the system is as follows: Priming signals are randomly inserted into each filter during the priming phase of operation; during steady state operation which is long compared with the priming phase, each time a signal is recognized by a channel of the adaptive filter it will be inserted into storage; during the priming and steady state phase, a third or examination phase takes place whereby the storage of the various adaptive filters are compared to assure that only one filter of the system will be recognizing a given signal.

WHAT WE CLAIM IS:—

1. A method for recognizing recurring signals with increasing accuracy and capable of distinguishing recurring signals

from random noise and other signals supplied by an input so that the identification of the recurring signals becomes progressively more accurate, comprising the steps of initially storing amplitude characteristics derived from the input consisting of time spaced values of input signal amplitudes, comparing the same characteristics derived from subsequent inputs with the stored characteristics and combining the subsequent characteristics with those in storage to provide revised stored characteristics if, and only if, a correlation exists between the compared characteristics, and repeating the comparing and combining steps whereby the recurring signals emerge from the other input signals.

2. A method according to claim 1 including deriving a correlation function and storing it as a threshold level whenever a correlation is detected, the characteristics of subsequent inputs being combined with those in storage if, and only if, the correlation function threshold level derived from subsequent inputs exceeds a predetermined fraction of the stored threshold level.

3. A method according to claim 2 in which said correlation function is derived as the sum of the products of the pairs of compared characteristics.

4. An adaptive signal recognition system for carrying out the method according to claim 1 comprising an adaptive filter having storage means for retaining an amplitude characteristic of the input, for a predetermined length of time, means for comparing the same characteristics of subsequent inputs with the stored characteristic, and combining means for altering the retained characteristic by the combination therewith of the same characteristic derived from subsequent inputs whenever correlation exists between the compared characteristics to achieve progessively better signal recognition.

5. An adaptive signal recognition system according to claim 4 having one or more channels for signal detecting in which each channel contains an adaptive filter receiving inputs from a tapped delay line, the adaptive filter comprising means connected to each tap for measuring an amplitude characteristic of the input, storage means for retaining one or more of the amplitude characteristics of previous inputs, and comparison means connected to compare the stored and measured characteristics, the means for altering the retained characteristic including combining means for combining the measured characteristic with the stored characteristic whenever the predetermined correlation exists between them.

6. An adaptive signal recognition system according to claim 5 wherein the comparing means is adapted to produce an output indicative of the correlation between the measured and stored characteristics, the comparing means being connected to a threshold detector to produce an output only when the comparing means produce an output signal whose amplitude exceeds a predetermined fraction of the amplitude of the previous maximum signal output therefrom, the combining means combining the stored and measured characteristics whenever the threshold detector produces an output signal.

7. An adaptive signal recognition system according to claims 5 or 6 wherein each measuring means and each storage means is connected to a corresponding multiplier, to provide an output which is the product of the amplitudes of the measured and stored characteristics, and the sum of the outputs of all multipliers is applied to the threshold detector to ascertain whether the required correlation exists with the previously stored characteristics.

8. An adaptive signal recognition system according to claims 5, 6 or 7 wherein a relay connects each measuring means to a tap on the delay line through a normally closed contact, each measuring means being connected to a corresponding storage means through a normally open contact on the relay; the storage and measuring means being connected through the relay only when the threshold detector produces an output signal. the output signal actuating the relay whereby the measured input characteristic is admitted to storage.

9. An adaptive signal recognition system according to claims 5 or 6 in which said channels are connected in parallel, each adaptive filter in each channel being capable of recognizing one of a plurality of signal inputs in which each tap in the delay line is connected to all adaptive filters and each adaptive filter is connected to inhibit means preventing more than one adaptive filter from recognizing the same signal, a separate inhibit means connected between the outputs of successive threshold detectors whereby the number of inhibit circuits required will be one less than the number of threshold detectors.

10. An adaptive signal recognition system according to any one of claims 5 to 9 wherein the storage and measuring means are capacitors, the capacity of the storage means being n times that of the measuring means, the charge on the storage means being indicative of k repetitions of a signal on the measuring capacitor, and the voltage on said storage means is weighted in favour of the k previous signals contained in said input by a factor of

$$\left(\frac{n}{n+1}\right)^k$$

11. An adaptive signal recognition system substantially as described with reference to Figures 1, 2, 3 and 4 or Figures 1, 3 and 5 or Figures 1, 3 and 6 of the accompanying drawings.

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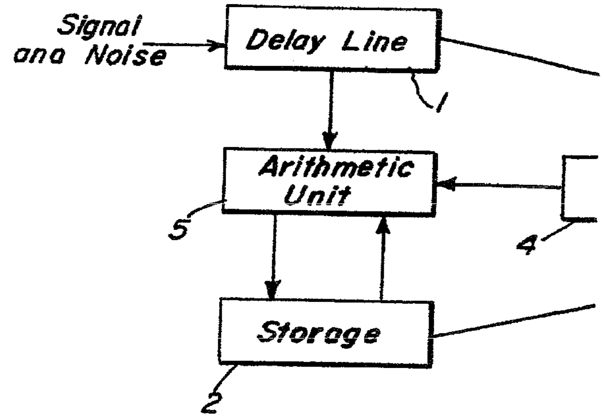
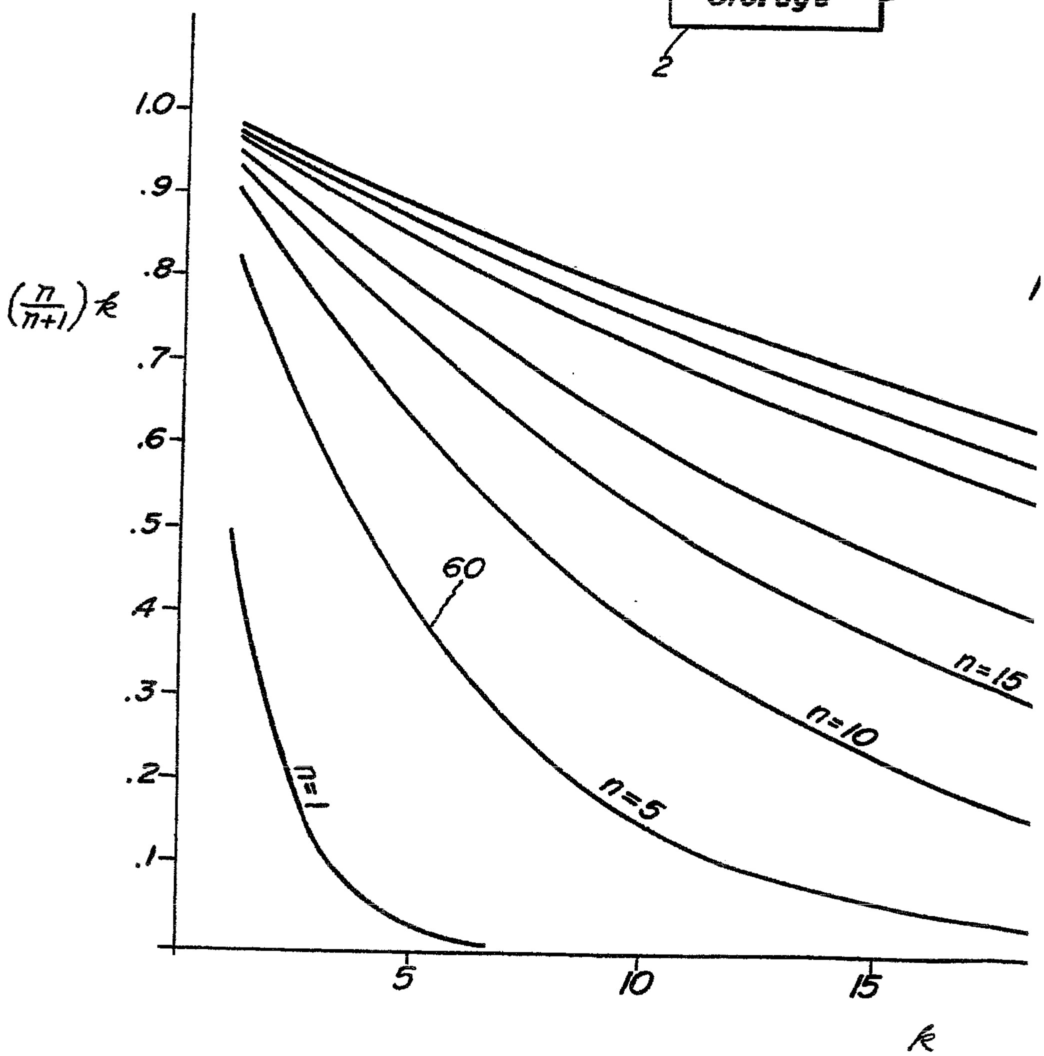


Signal and Noise
Delay Line
1
Arithmetic Unit
5
4
Storage
2



1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
$\left(\frac{n}{n+1}\right)k$
60
n=1
n=5
n=10
n=15
5
10
15
k

971,109 COMPLETE SPECIFICATION
4 SHEETS This drawing is a reproduction of the Original on a reduced scale.
SHEET 1

Fig. 1.

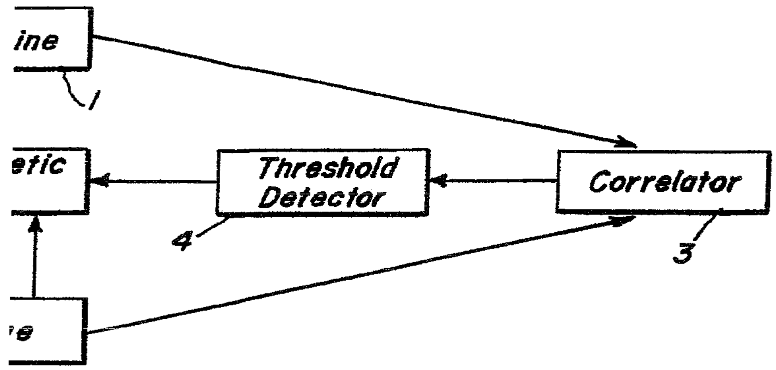


Fig. 4.

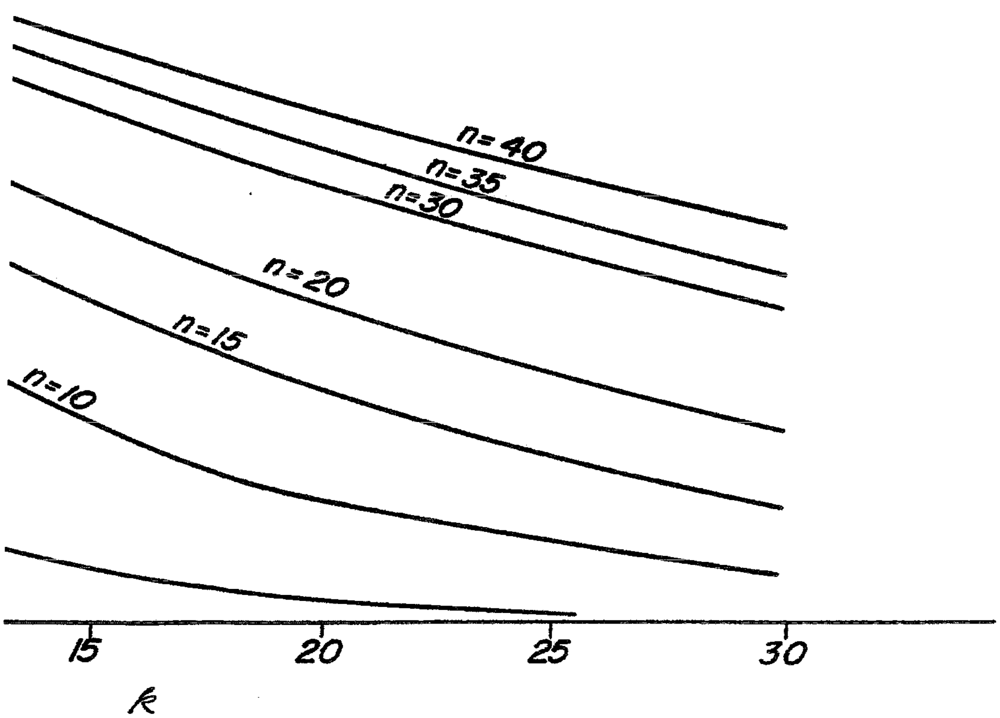


Fig. 1.

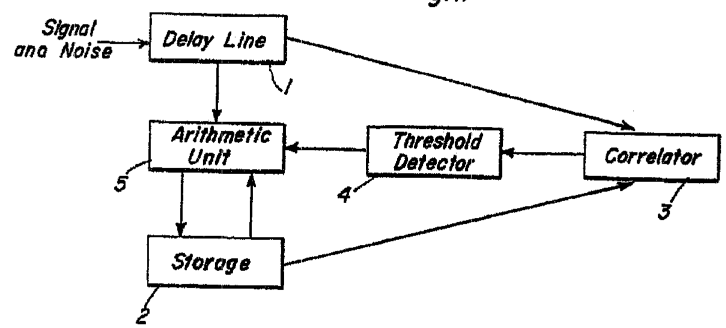

Signal and Noise
Delay Line
1
Arithmetic Unit
5
Threshold Detector
4
Correlator
3
Storage
2

Fig. 4.

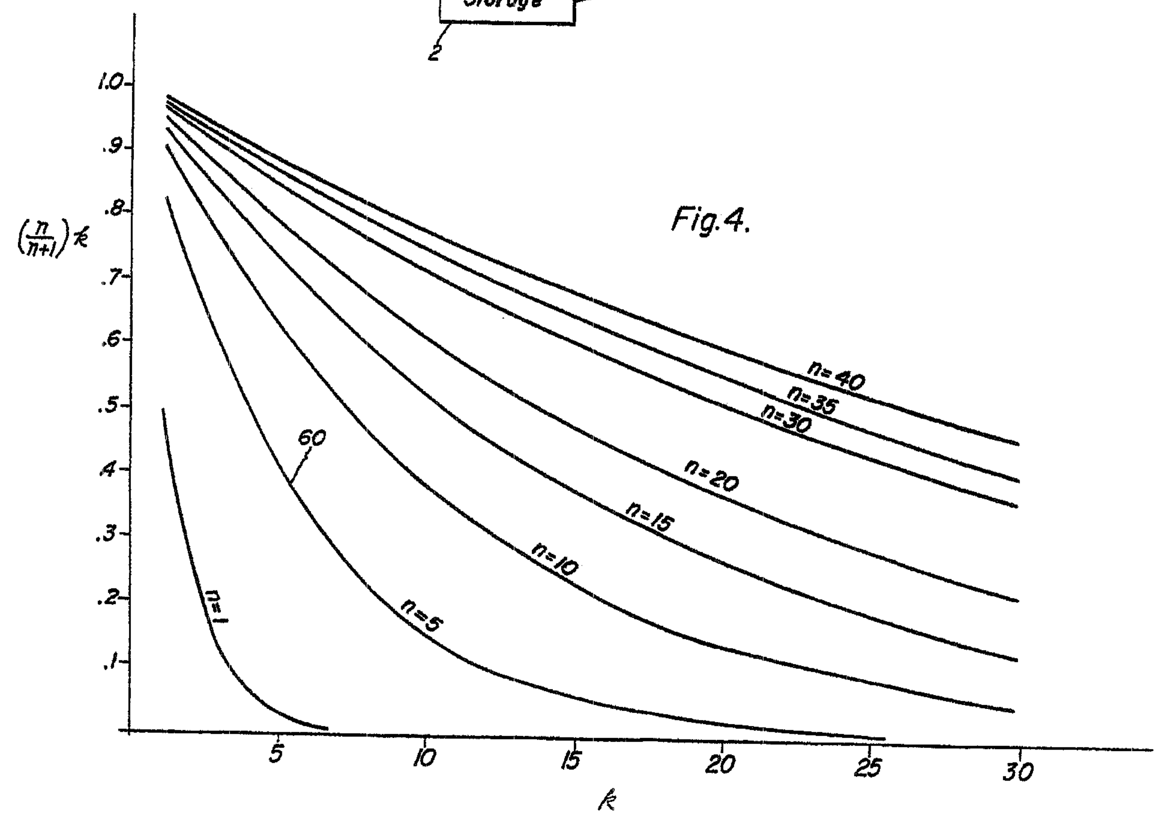
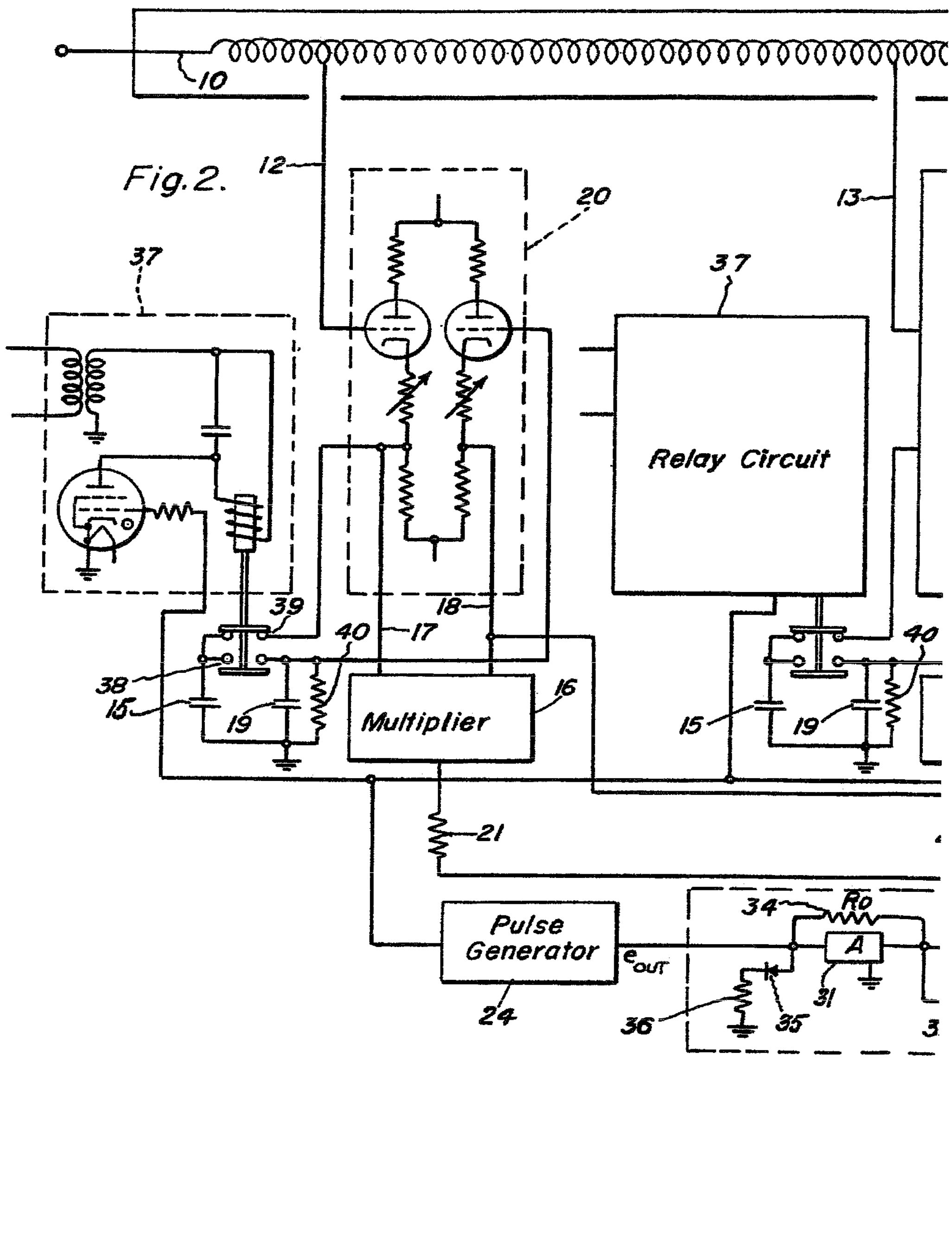
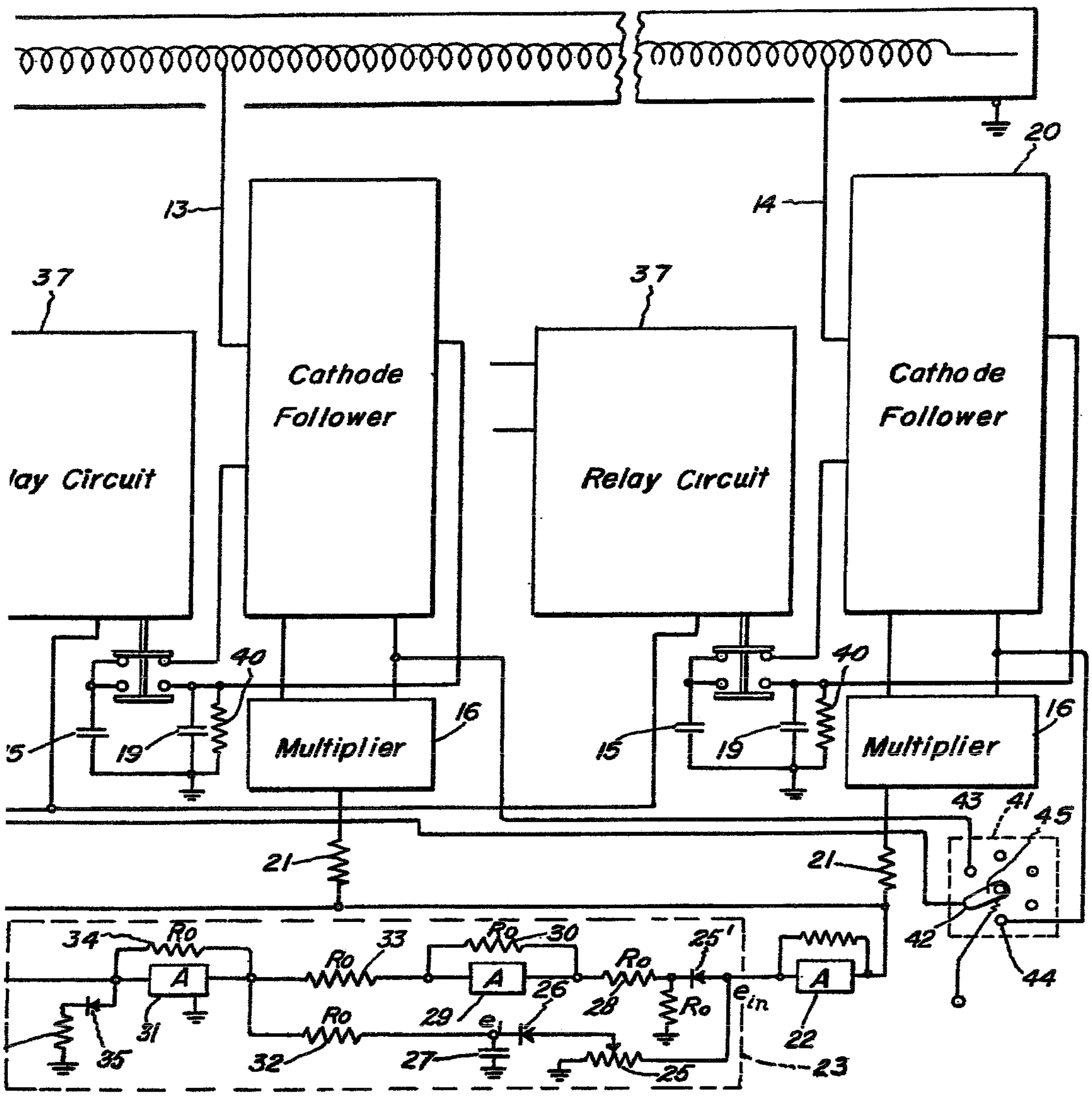

$\left(\frac{n}{n+1}\right)^k$
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
n=40
n=35
n=30
n=20
n=15
n=10
60
n=5
n=1
5
10
15
20
25
30
k

Fig. 2.


10
12
13
20
37
37
Relay Circuit
39
38
40
40
17
18
15
15
19
19
Multiplier
16
21
Pulse Generator
24
e_{OUT}
34
Ro
A
31
35
36


13
14
20
37
37
Cathode Follower
Cathode Follower
lay Circuit
Relay Circuit
40
40
Multiplier
Multiplier
16
16
15
19
19
21
21
43
41
45
42
44
34
Ro
33
Ro
30
25'
28
29
26
31
35
32
27
25
22
23
A
A
A
e
e_{in}

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SHEET 2

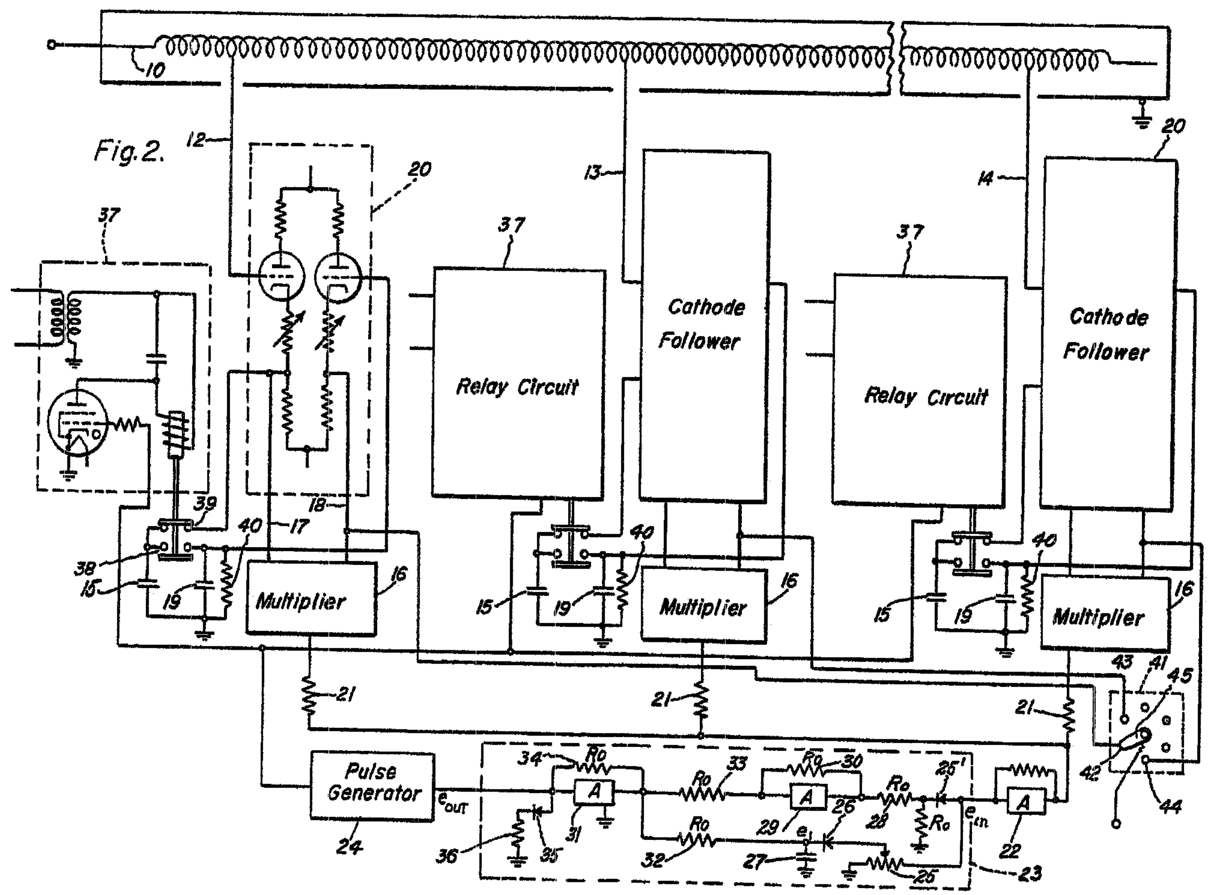
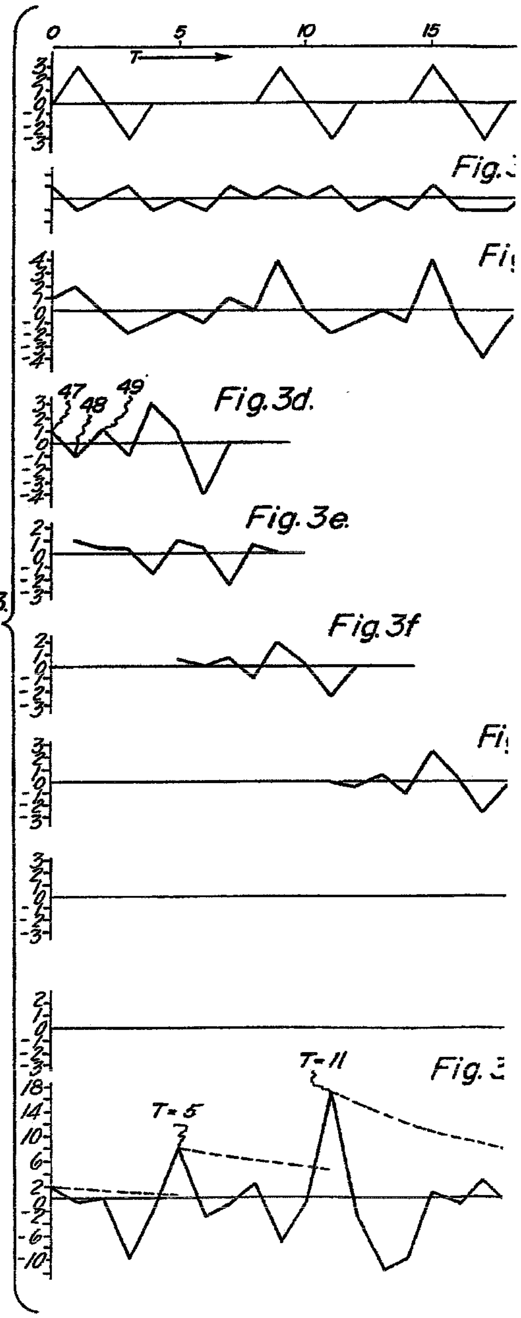


Fig. 2.

Fig.3



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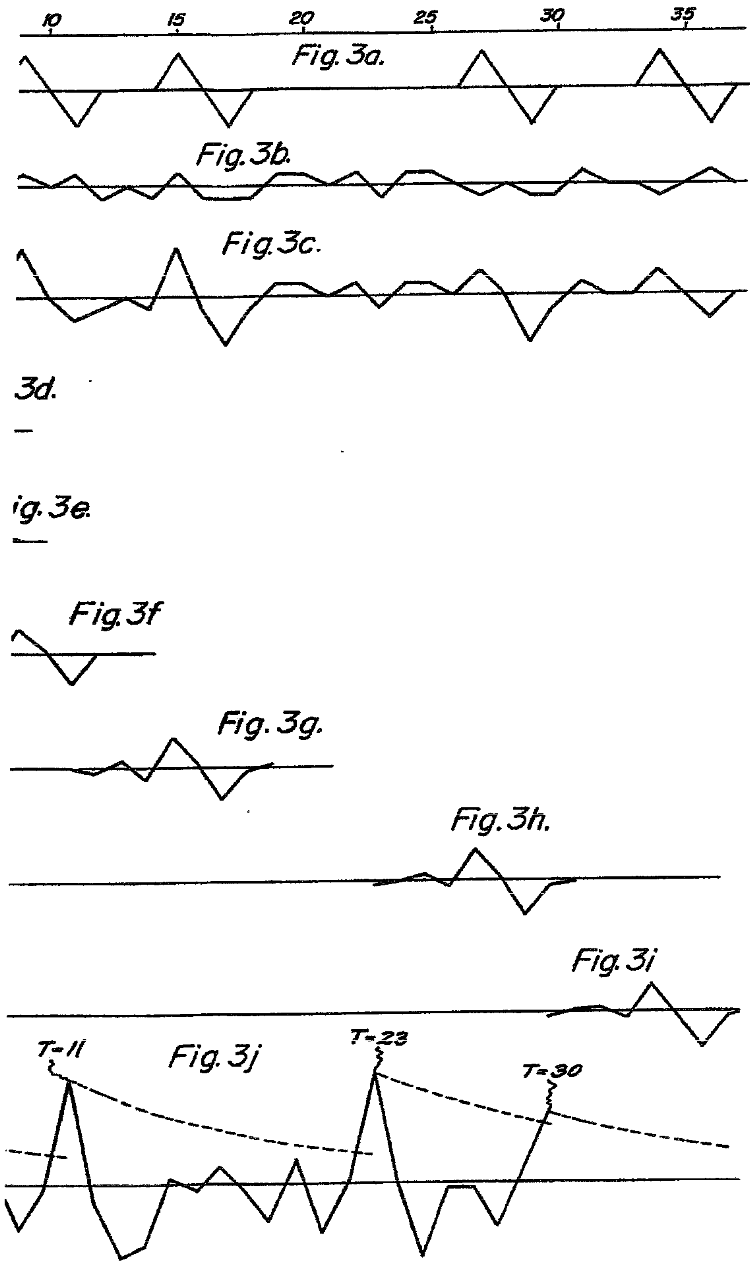
SHEET 3



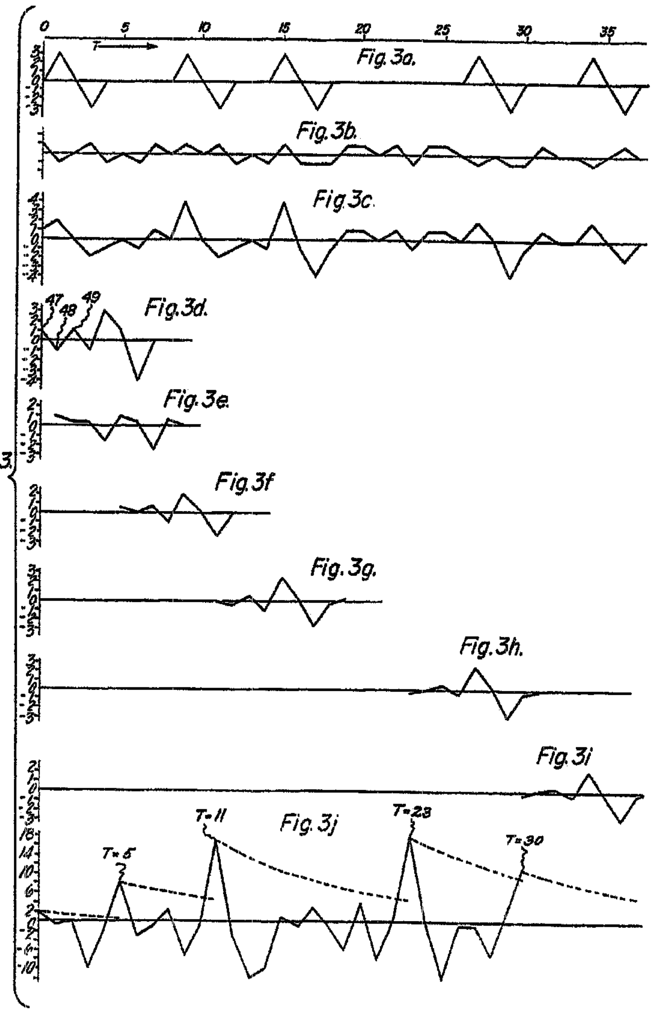
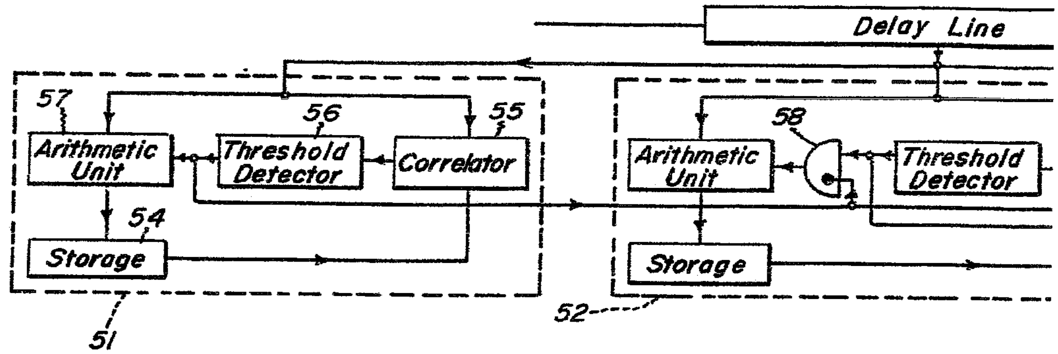


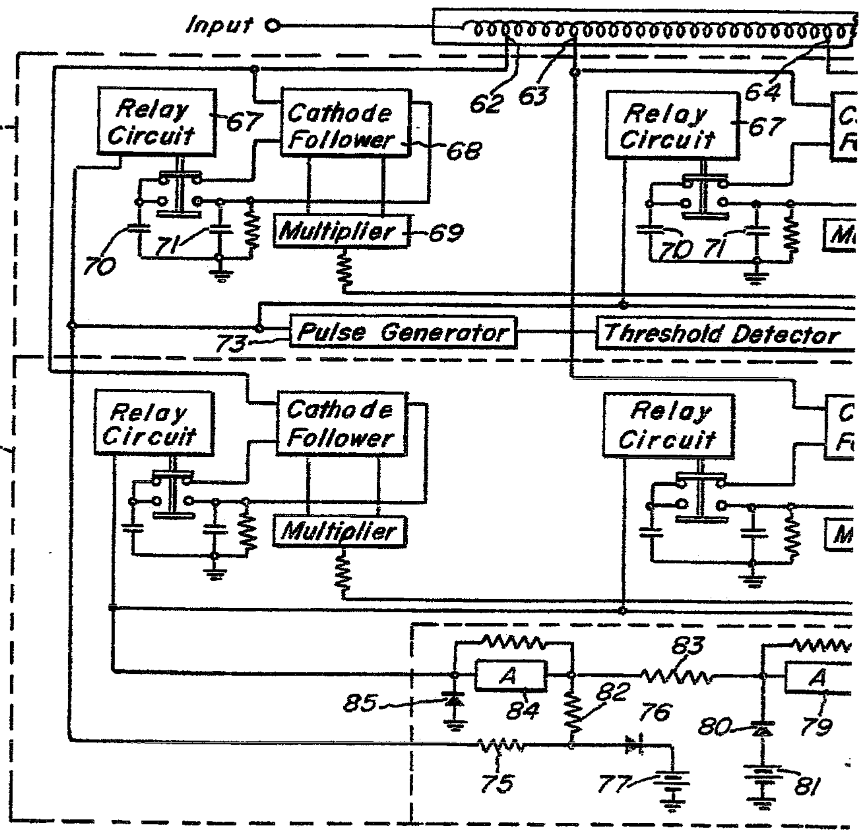
Fig. 3a.
Fig. 3b.
Fig. 3c.
Fig. 3d.
47
48
49
Fig. 3e.
Fig. 3f
Fig. 3g.
Fig. 3h.
Fig. 3i
Fig. 3j
T=5
T=11
T=23
T=30
T

Fig. 3



Delay Line
Arithmetic Unit
Threshold Detector
Correlator
Storage
Arithmetic Unit
Threshold Detector
Storage
57
56
55
54
58
51
52

Fig. 6.



Input
Relay Circuit
Cathode Follower
Multiplier
Relay Circuit
Pulse Generator
Threshold Detector
Relay Circuit
Cathode Follower
Multiplier
Relay Circuit
A
A
62
63
64
65
66
67
68
69
70
71
73
75
76
77
79
80
81
82
83
84
85

971,109 COMPLETE SPECIFICATION
4 SHEETS
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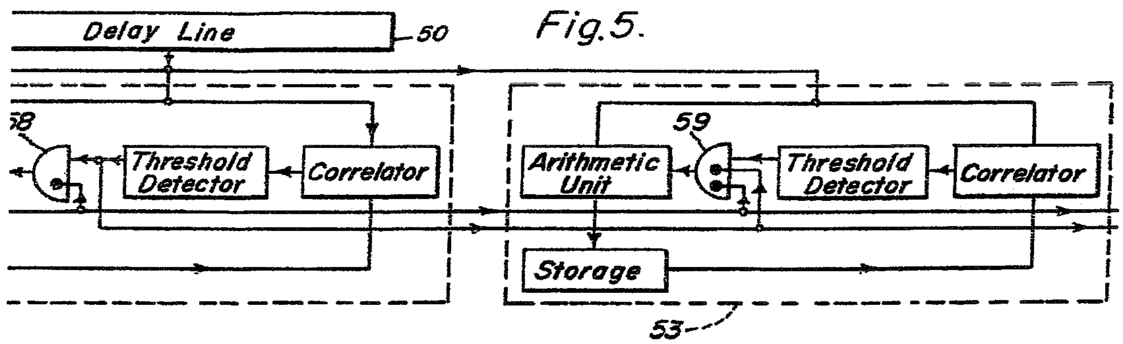
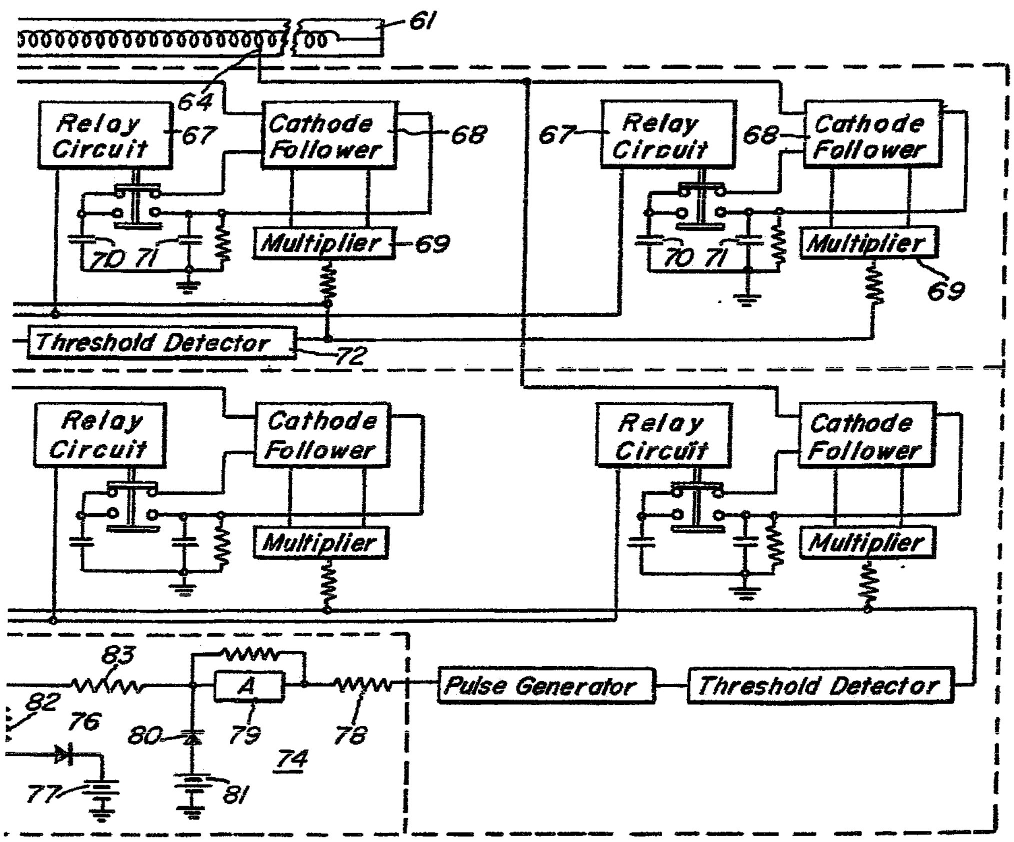
SHEET 4

Fig. 5.





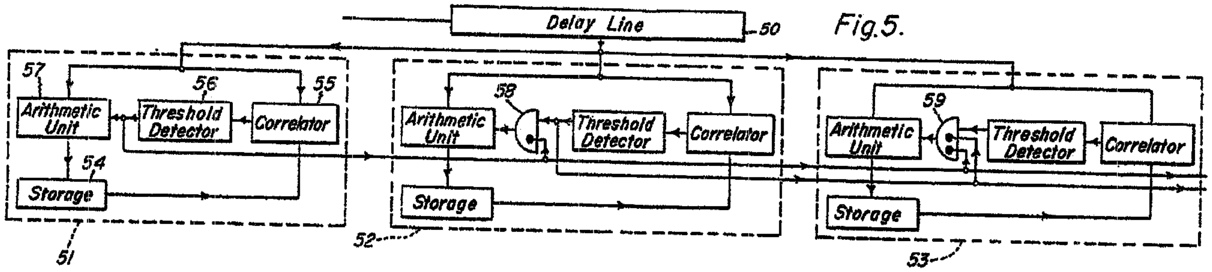
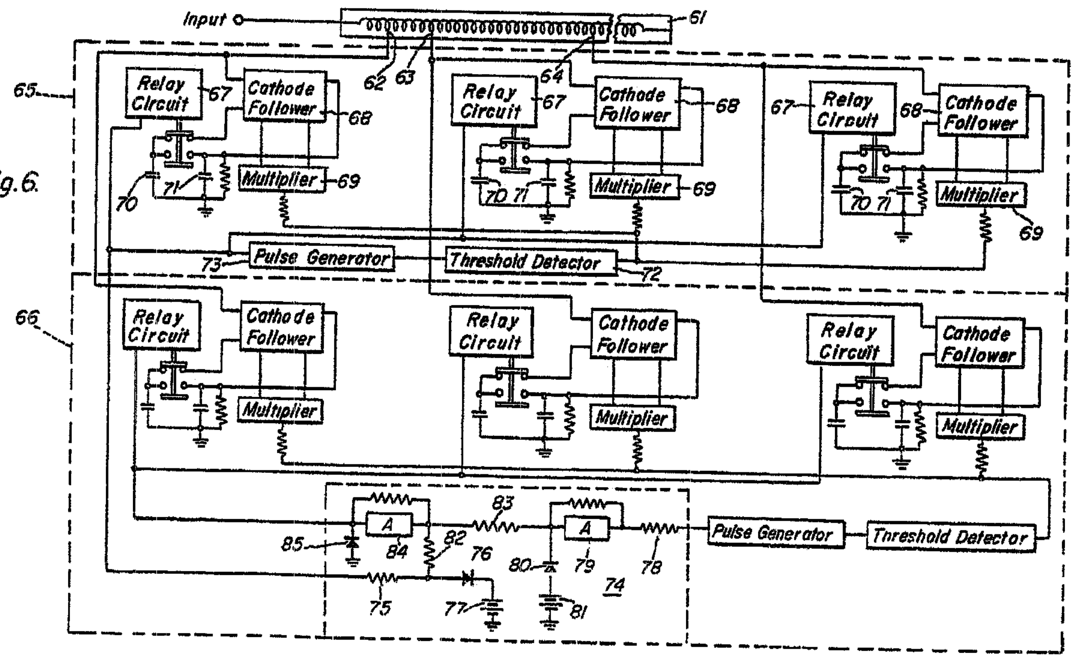

Delay Line
50
57
56
55
Arithmetic Unit
Threshold Detector
Correlator
54
Storage
51
58
Arithmetic Unit
Threshold Detector
Correlator
Storage
52
59
Arithmetic Unit
Threshold Detector
Correlator
Storage
53

Fig.5.


Input
61
62
63
64
65
66
Relay Circuit
Cathode Follower
Multiplier
67
68
69
70
71
Pulse Generator
Threshold Detector
72
73
A
74
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85

Fig.6.